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Analytical Approach for Quantifying Noise from Advanced Operational Procedures

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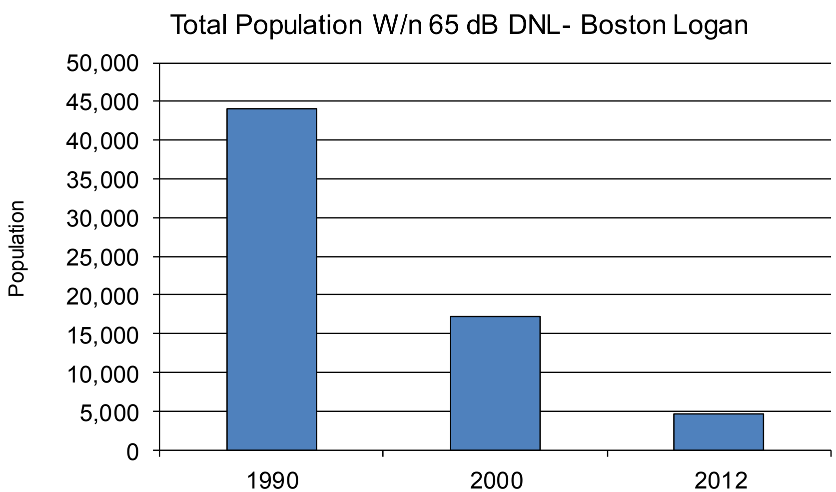
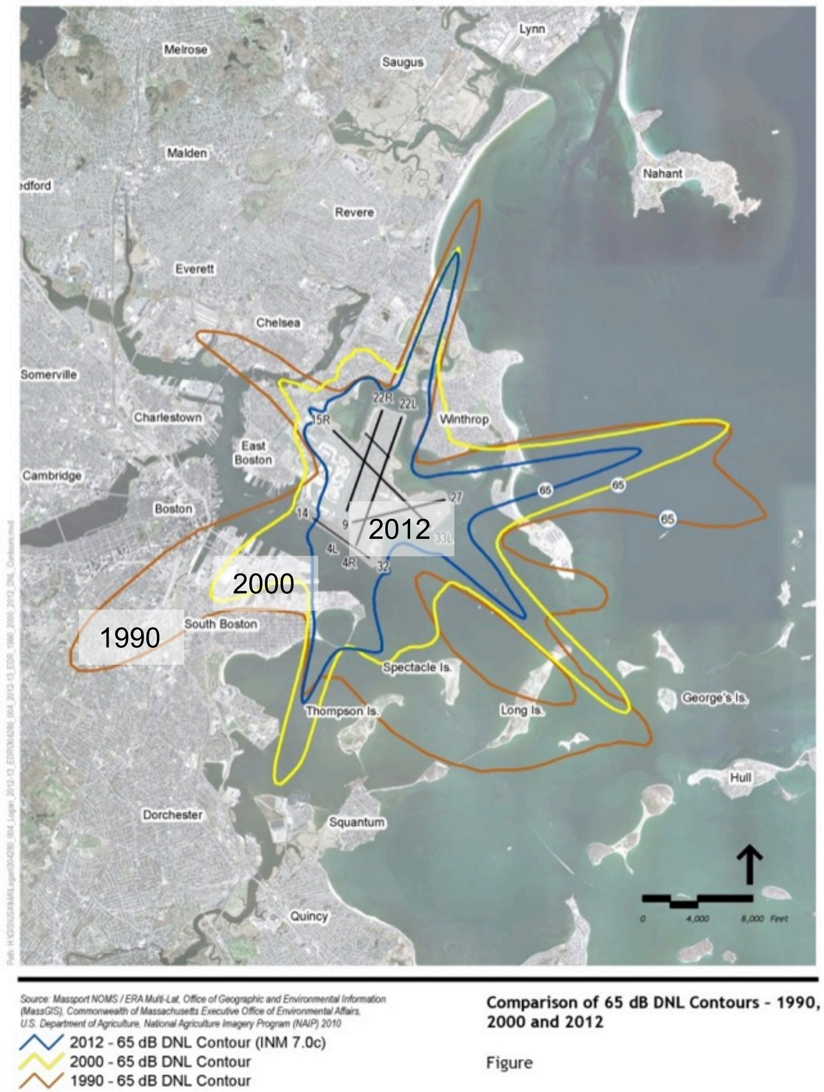
Motivation

- **Significant reductions in population exposure to airport noise have been made over the past 25 years**
  - Reduced engine noise
  - Noise abatement procedures
- **Further noise footprint reduction may be possible through operational adjustments**



Note: 65db DNL is FAA's designation of significant noise exposure.



Source: Massport

Potential for Continued Noise Improvements

- **Advanced operational departure procedures**
  - Flight path adjustments
  - Derated takeoff thrust
  - Thrust cutback scheduling

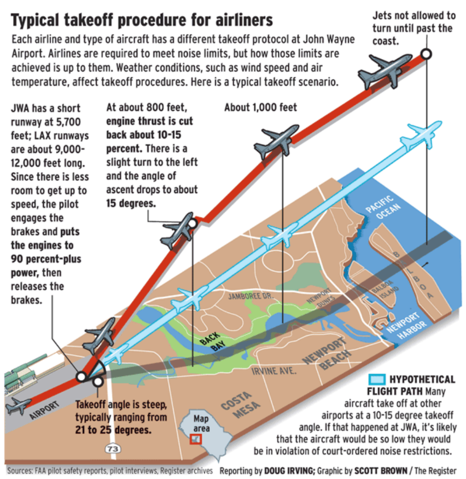


Figure: The Orange County Register

- **Advanced operational approach procedures**
  - Continuous descent/steep approaches
  - Delayed deceleration approaches
  - RNAV/RNP approach trajectories

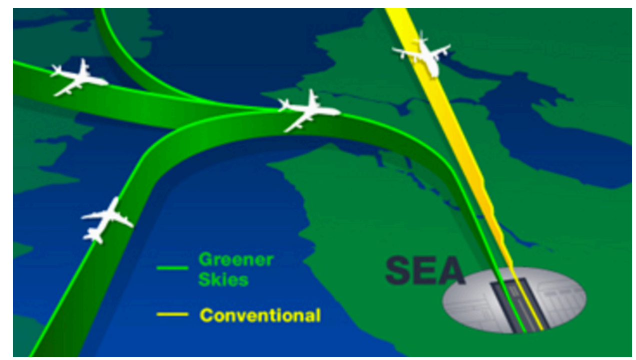


Figure: FAA.gov

- **New Aircraft Configurations**
  - Cleaner Airframes
  - Engine Noise Shielding Effects

Figure: D8 Aircraft Concept, from NASA.gov

Project Goal

- **Current industry standard noise analysis methods do not fully capture noise impacts from aircraft configuration or other operational techniques**
- **Traditional aircraft noise analysis assumes that engine noise dominates aerodynamic noise**
  - Assumption may have been valid for earlier generation jet engines

Project Goal: to expand analysis capabilities to enable the modeling the noise impacts of advanced operational procedures and aircraft configuration

Current Analysis Methods: Aircraft Environmental Design Tool (AEDT)

- **Industry standard model that evaluates aircraft noise impacts in the vicinity of airports**
  - Normally used for DNL analysis
- **Simple physics model**
  - Low resolution
    - Not intended for high-fidelity single event modeling
  - Considers “Average Annual Day”
  - Assumes consistent sound energy dissipation with distance
  - Only considers atmospheric noise propagation
  - Does not capture shielding effects well
- **Noise-Power-Distance (NPD) based**

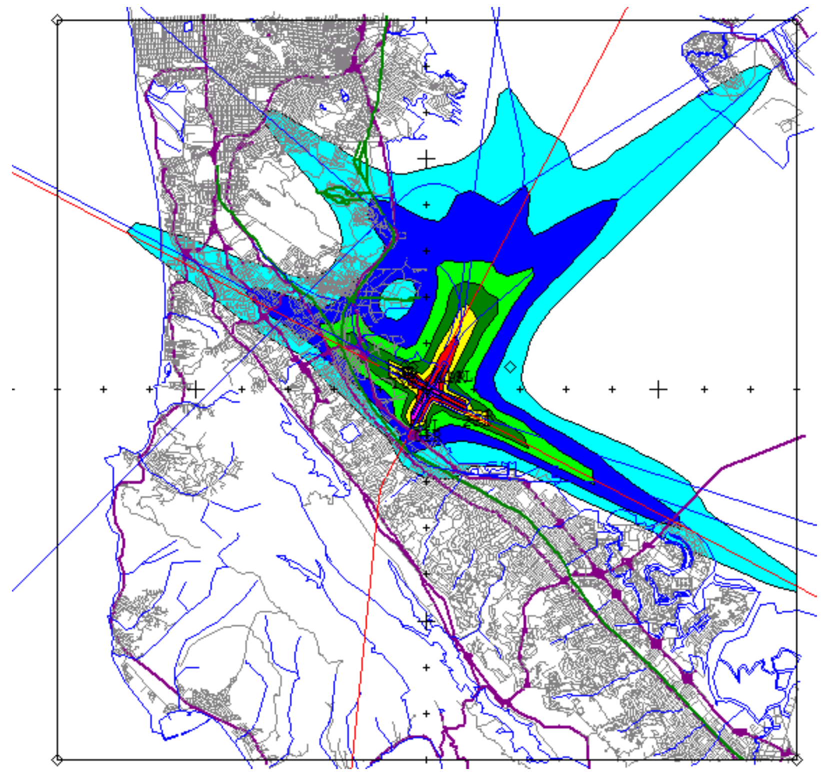
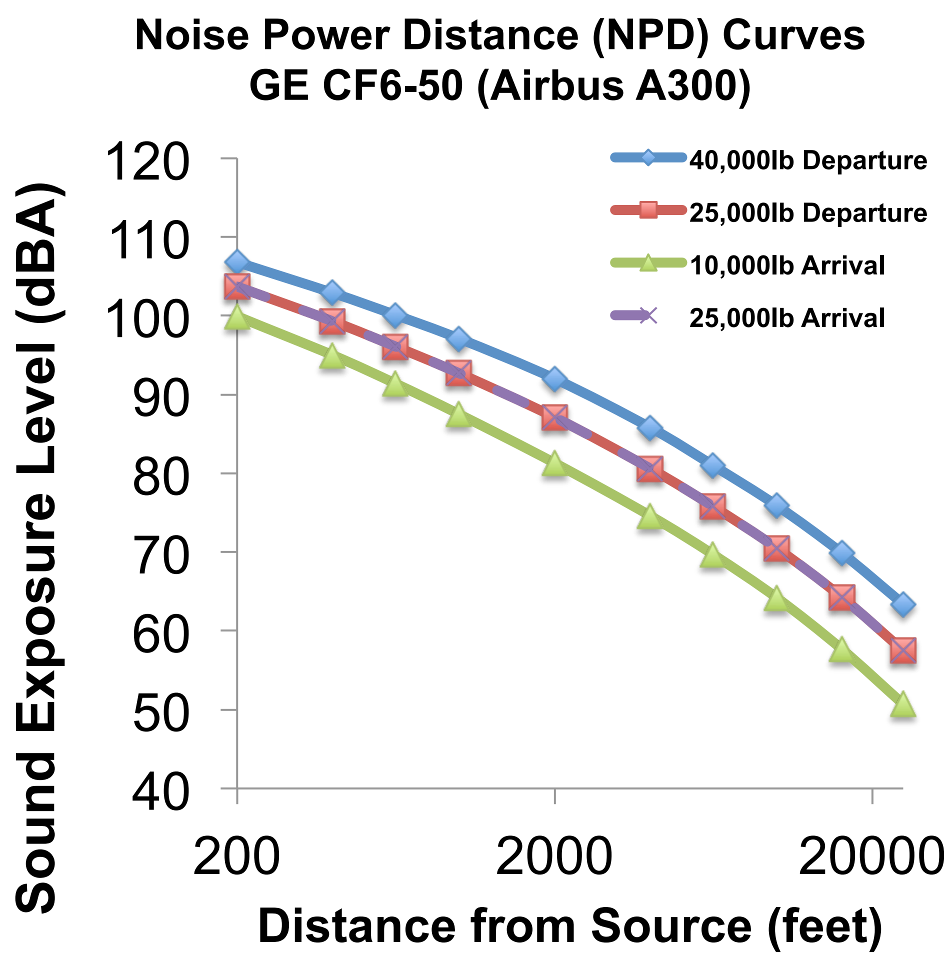


Figure: INM Technical Manual

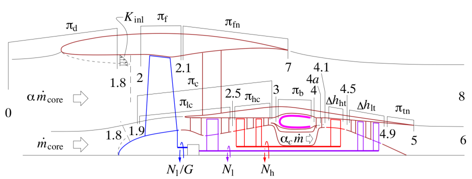
Noise-Power-Distance Approach

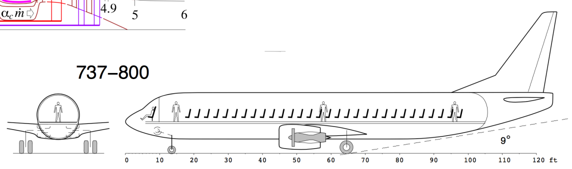
- **Single-event noise exposure calculated for each arrival/ departure segment**
- **Requires thrust and distance interpolation from limited flight test data**
- **Crude accounting for different flap, landing gear settings**
  - High-power approach curves assume dirty landing configuration
  - Ignores velocity effects on aerodynamic noise



TASOPT and ANOPP Noise Modeling Approach

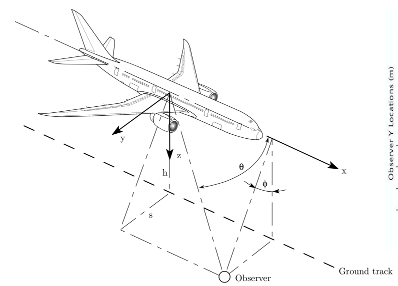
Transport Aircraft System OPTimization (TASOPT)

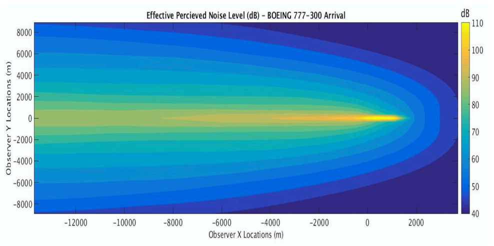




- **Written by Prof. Mark Drela (MIT)**
- **Physics-based optimization program**
- **Based on mission requirements, generates an optimal transport aircraft design, including:**
  - Engine performance and geometry
  - Aircraft performance and geometry

Aircraft NOise Prediction Program (ANOPP)





- **NASA-developed program**
- **Computes far-field engine and airframe noise at an observer grid given various flight profile and configuration metrics**
  - Semi-empirical calculations require detailed engine/aircraft performance inputs
    - e.g., Engine mass flow, areas, and temperatures, airframe geometry, etc.
- **Models shielding, propagation effects**

TASOPT - ANOPP Noise Analysis Framework

TASOPT Inputs:
Operating/mission parameters
Aircraft sizing/performance parameters
Engine sizing/performance parameters

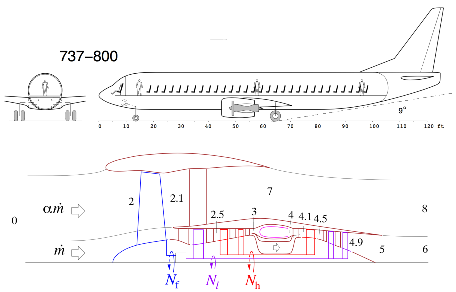
Flight Procedure Type:
Flight Path Angles
Velocity
Configuration

**Flight Procedure Generator* a force-balance model to determine required thrust levels given:
- User flight profile requirements
- TASOPT aircraft performance characteristics

TASOPT

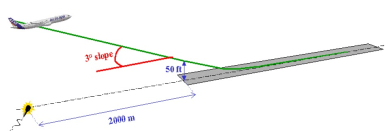
Flight Procedure Generator*

TASOPT Outputs:



Aircraft/engine performance & geometry

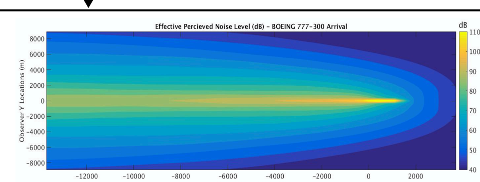
Flight Procedure:
Thrust, velocity, position, gear/flap settings per time



ANOPP Control Inputs:
Propagation settings
Observer locations

ANOPP

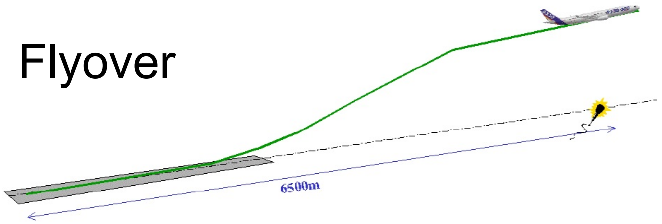
Noise contours for each observer location



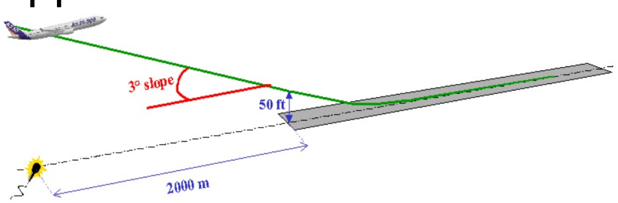
Noise Certification Data Comparison Overview

- **Effective Perceived Noise Level (EPNL) of known aircraft computed in ANOPP**
  - Results compared to FAA certification noise data (reported in 14 CFR Part 36) for those aircraft for validation
- **EPNL reported at 3 observer locations: Flyover, Approach and Sideline**
- **Fight profile requirements:**
  - Flyover:
    - **Thrust:** Max TO to altitude 300m, then reduced to maintain 4% climb grad
    - **Velocity:** V2+10kt to V2+20kt
  - Approach:
    - **Thrust**: required to maintain 3° glide slope
    - **Velocity:** Vref+10kt
  - Sideline:
    - **Thrust:** Max TO
    - **Velocity:** V2+10kt to V2+20kt

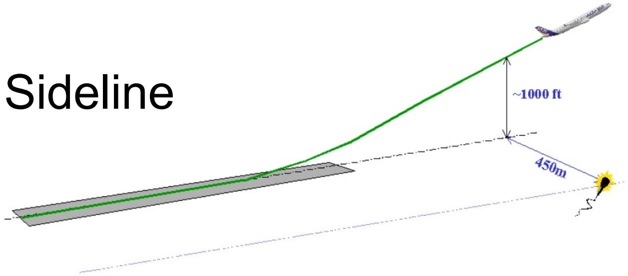
Flyover



Approach

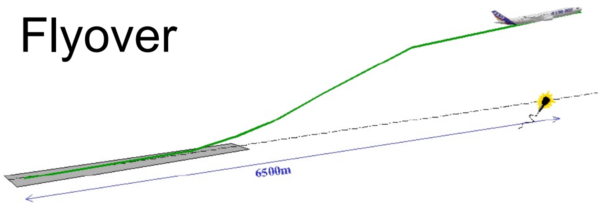


Sideline

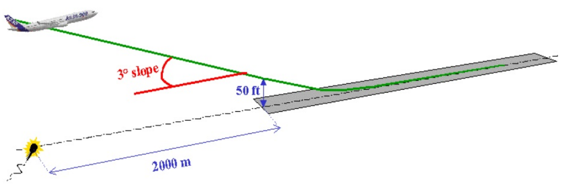


Current Validation Results

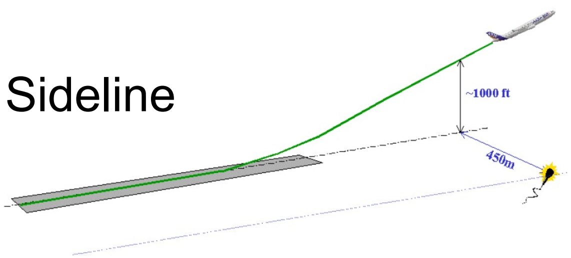
Flyover



Approach



Sideline



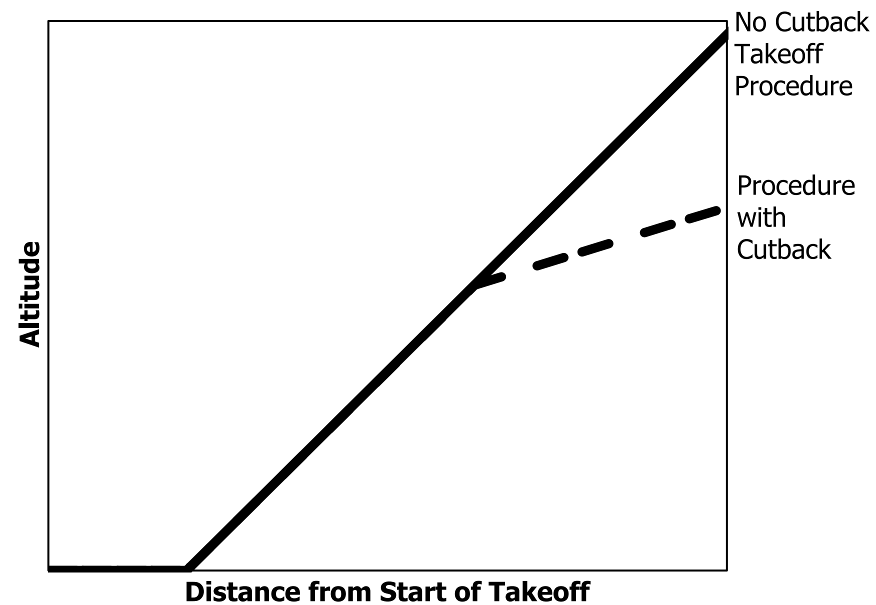
		ANOPP Calculated Effective Perceived Noise Levels (dB)	FAA Certification Noise Data (dB)	Error (dB)
Boeing 737-800 TO/AP Wt: 172300/146300 lbs Engine: CFM56-7B26	Flyover	87	86.7	+0.3
	Approach	96.11	96.8	-0.69
	Sideline*	97.61	93.1	+4.51
Boeing 777-300 TO/AP Wt: 636100/524000 lbs Engine: RR Trent 892	Flyover	94.87	94.2	+0.61
	Approach	101.3	100.4	+0.9
	Sideline*	99.88	96.9	+2.98
Embraer 195 TO/AP Wt: 111970/99200 lbs Engine: CF34-10E5	Flyover	87.46	86.5	+0.96
	Approach	92.55	92.8	-0.25
	Sideline*	98.72	91.8	+6.92

- *Sideline noise error likely due to jet exhaust temperature over-prediction in TASOPT (required input for the ANOPP jet noise calculation) for max thrust conditions
  - Calculated sideline noise error is reduced to within +/- 1 dB EPNL for each aircraft with an 8% reduction in TASOPT outputted jet exhaust temperatures

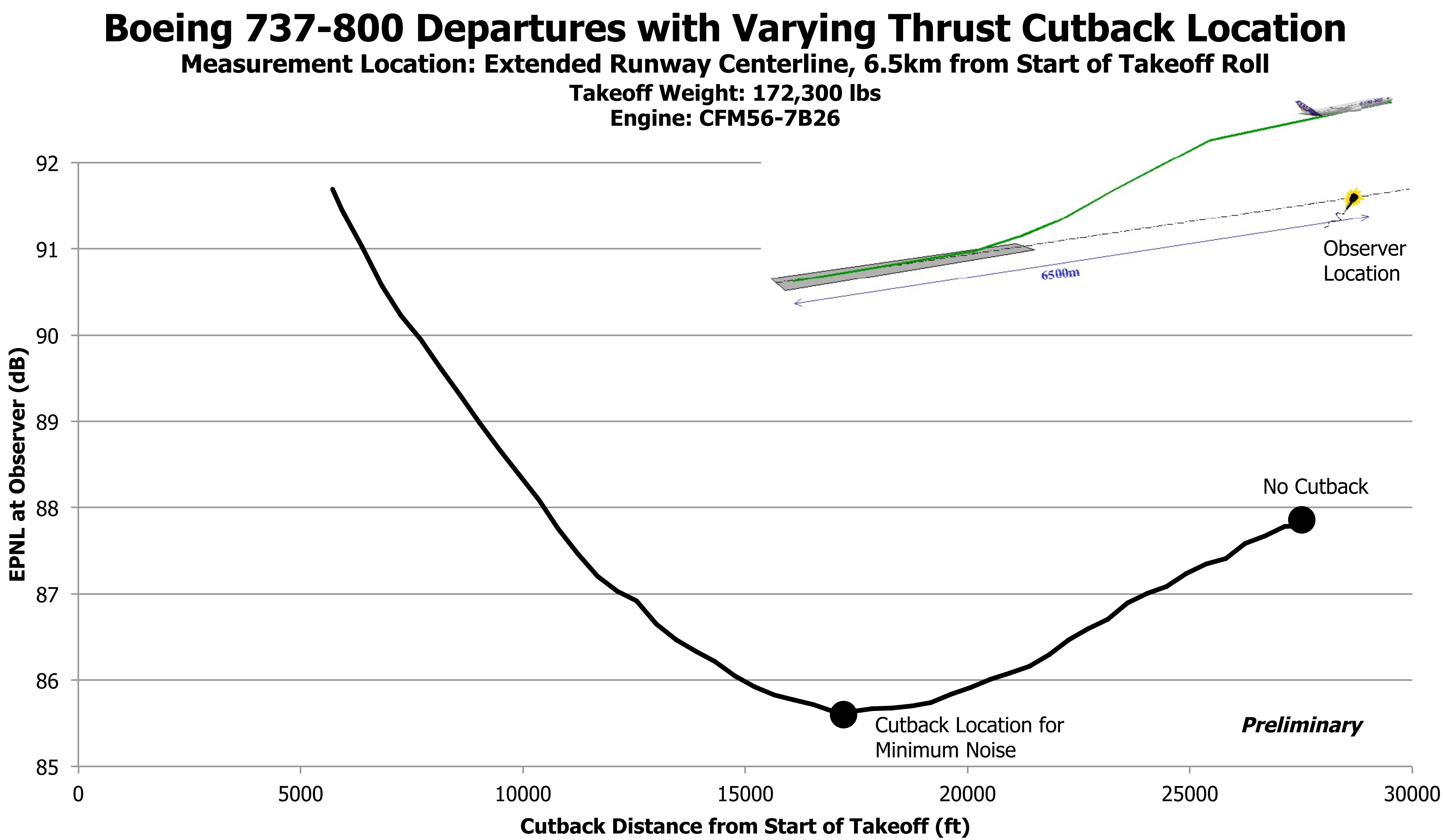
Example Application: Thrust Cutback Location on Departure

- **Typical takeoff procedure uses constant takeoff thrust throughout initial climb segment**
  - Safety & efficiency benefits
- **Thrust cutback after takeoff during initial climb can be used to reduce noise for nearby communities**
  - Specific location of cutback determines overall noise impact of procedure

Variation of Departure Flight Profile with Thrust Cutback Location



Impact of Thrust Cutback Location on Single-Observer Departure Noise



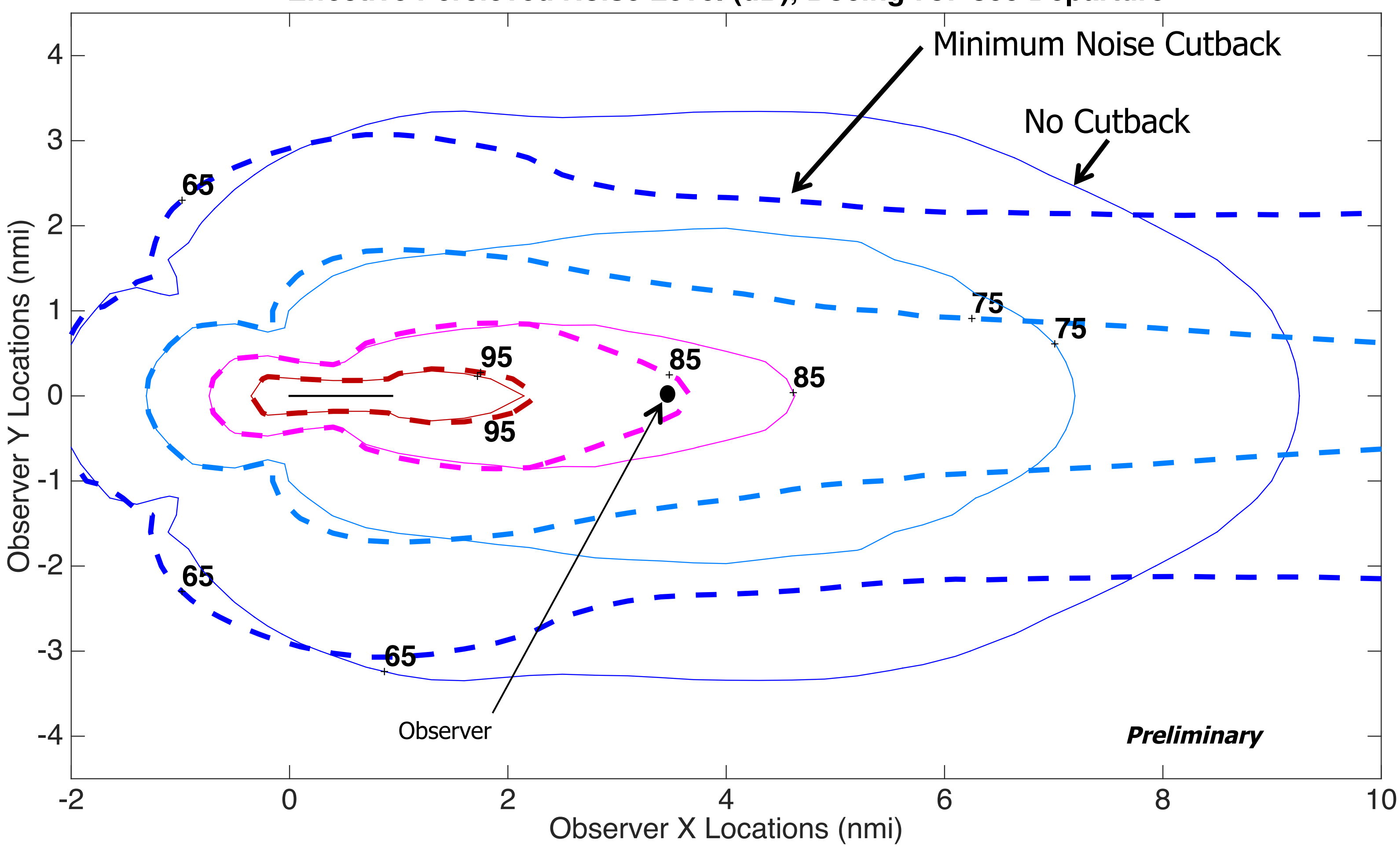
Impact of Thrust Cutback Location on Departure Noise Contour Geometry

Boeing 737-800 Departure Profiles

Takeoff Weight: 172,300 lbs

Engine: CFM56-7B26

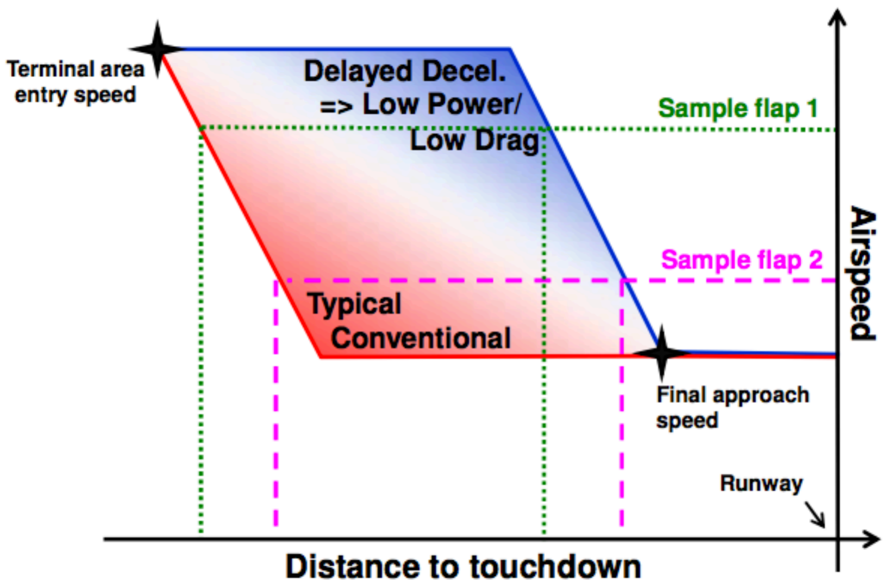
Effective Percieved Noise Level (dB), Boeing 737-800 Departure



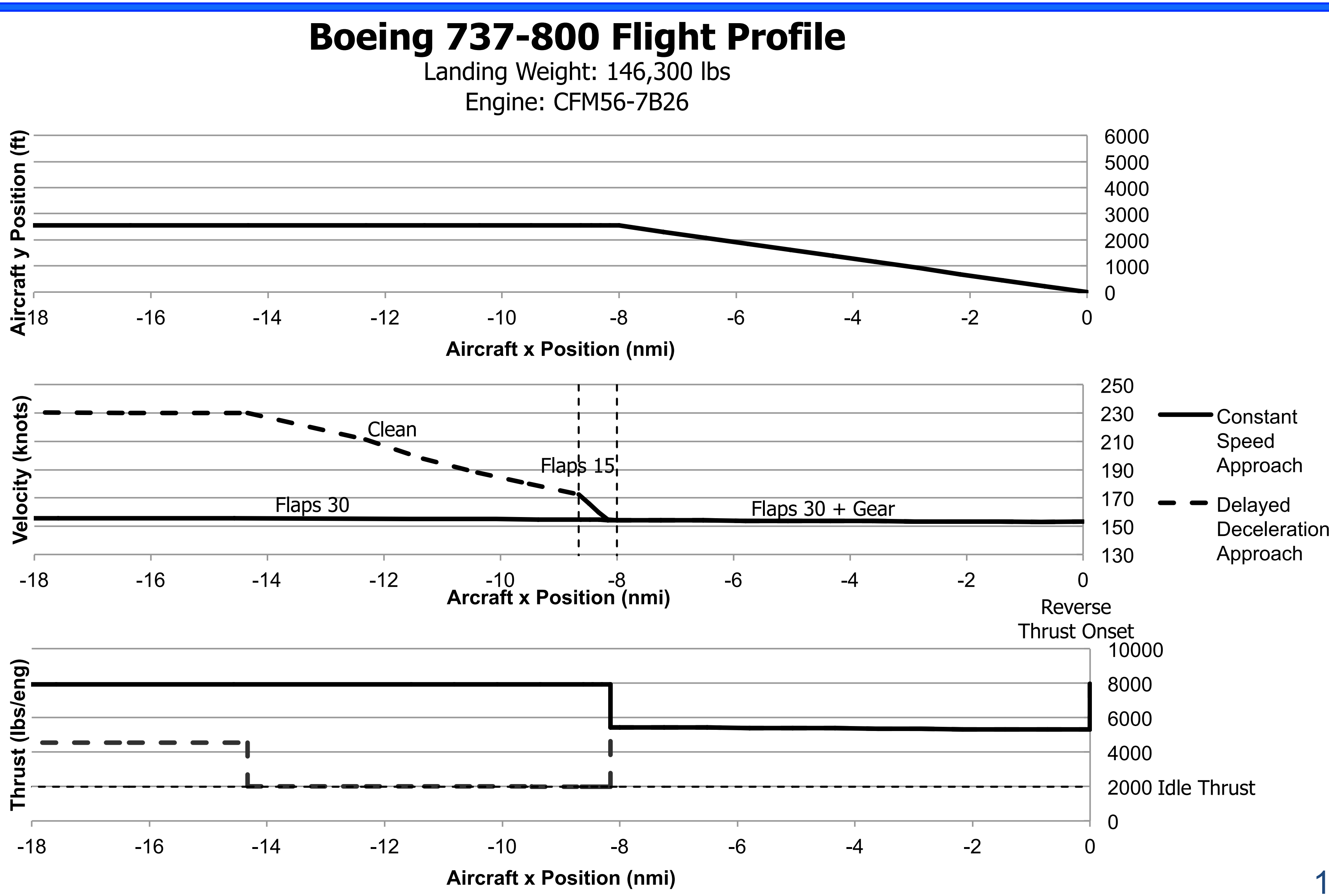
Example Application: Delayed Deceleration Approach

- **In conventional approaches aircraft decelerate early in the approach**
  - Often commanded by air traffic control for spacing traffic flows
- **In DDA approaches, initial flap speed velocity held as long as possible during approach to lower drag and thrust requirements**
  - Lower thrust levels and reduce engine noise
  - Higher velocities increase airframe noise

Conventional vs. DDA Approach



Delayed Deceleration Approach Profile: Glideslope Intercept from Level Flight

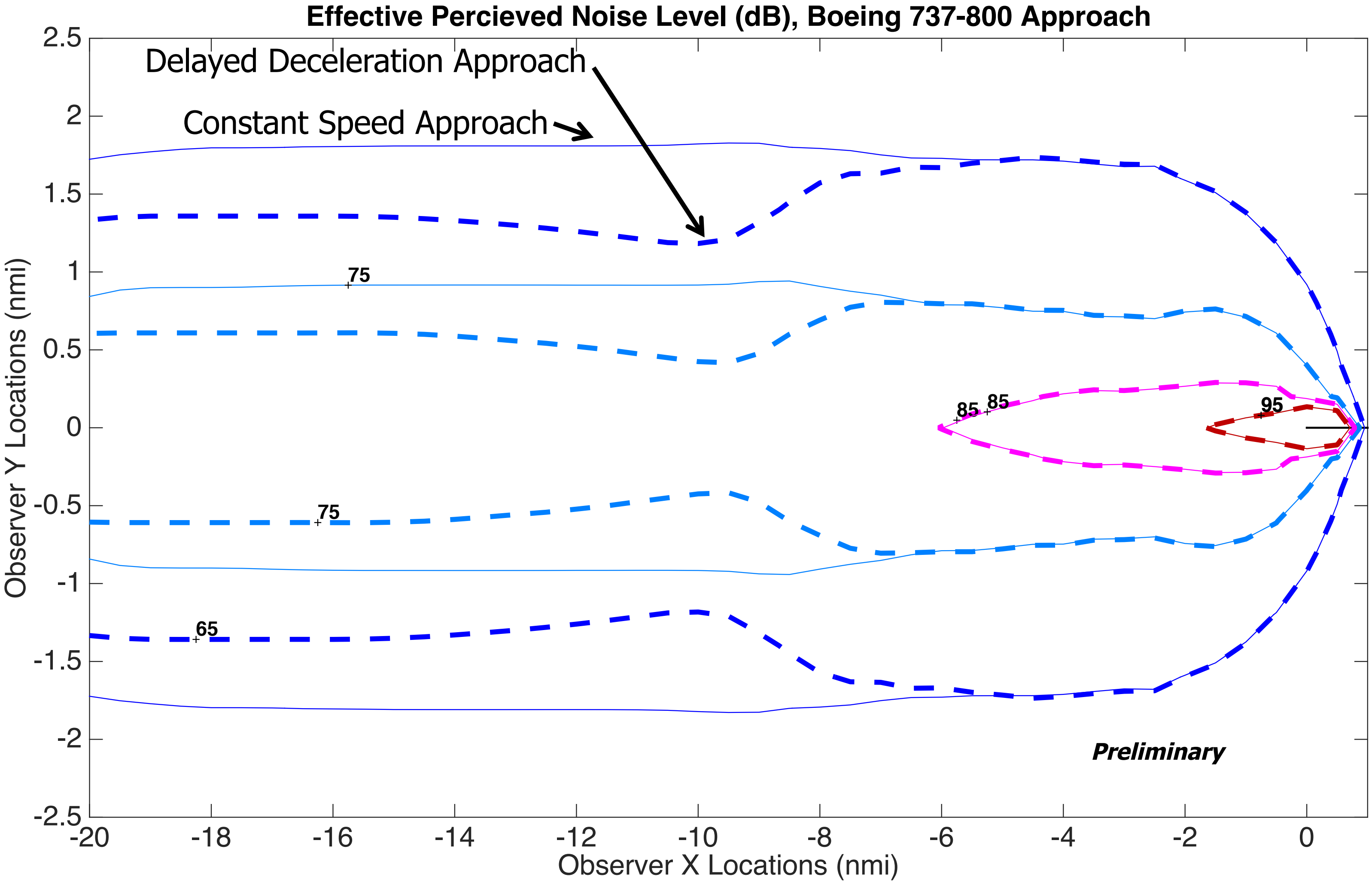


Impact of Delayed Deceleration Approach on Noise Contour Geometry

Boeing 737-800 Flight Profile

Landing Weight: 146,300 lbs

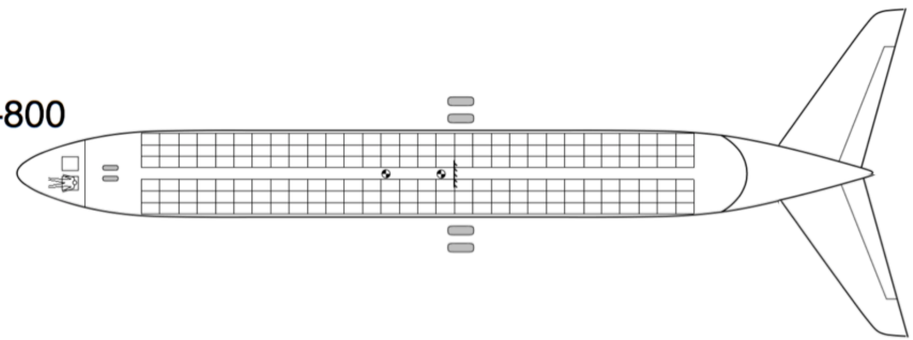
Engine: CFM56-7B26



Example Application: Modeling New Aircraft Configurations

- **New aircraft configurations, compared to existing baseline aircraft with the same passenger number and range requirements, may feature:**
  - Cleaner, lighter airframes, engine noise shielding
  - Reductions in fuel burn, emissions, community noise

737–800



D8.2

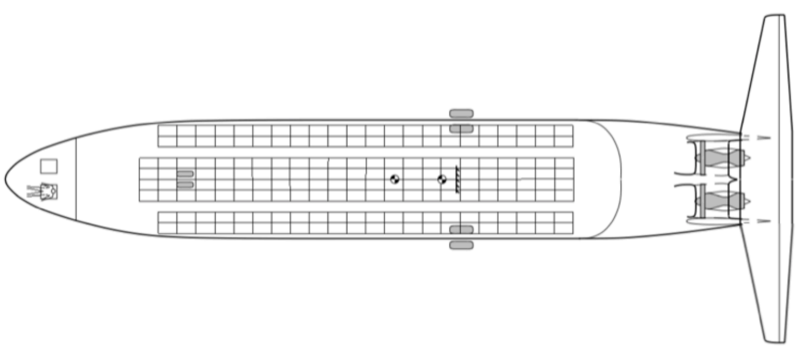
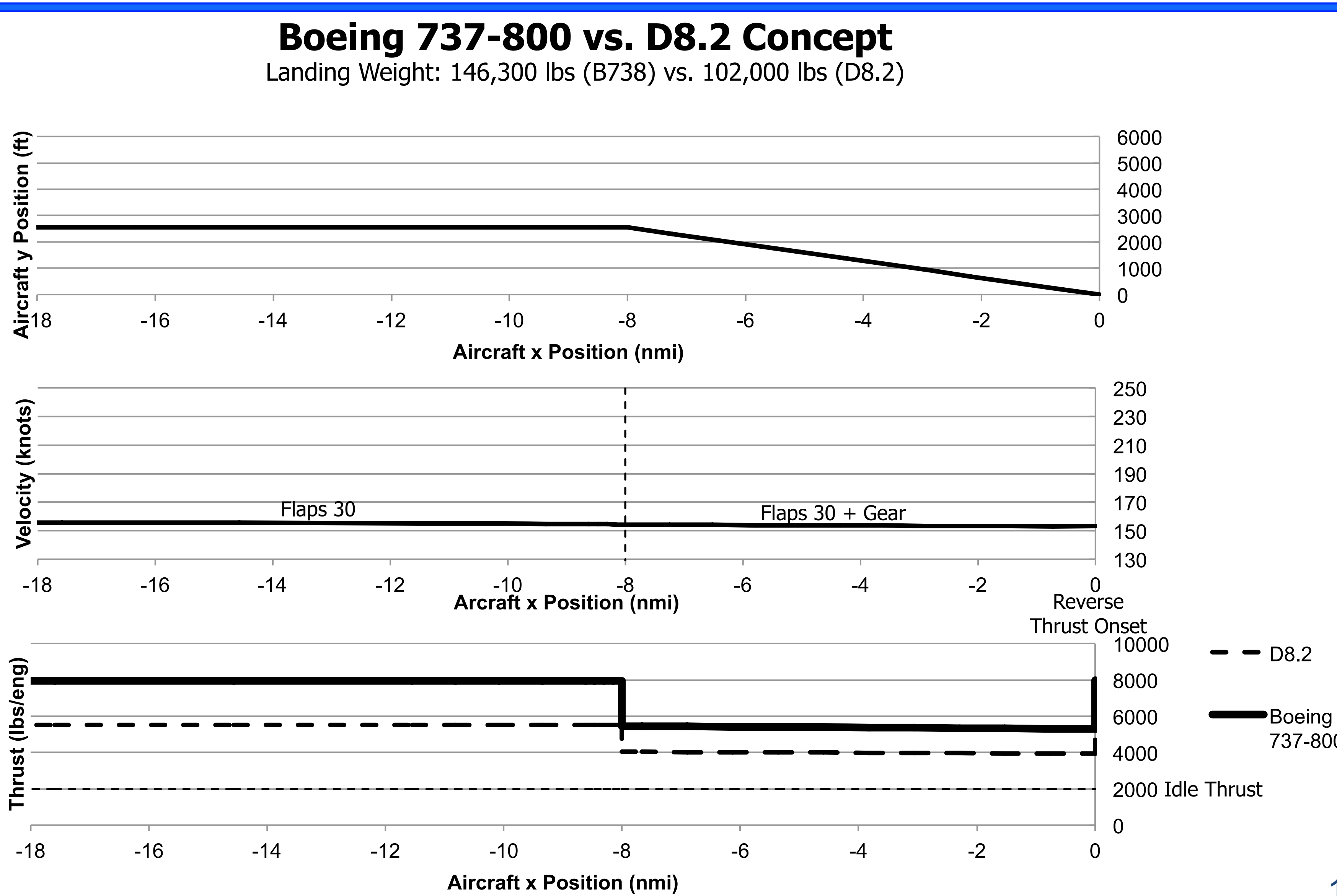


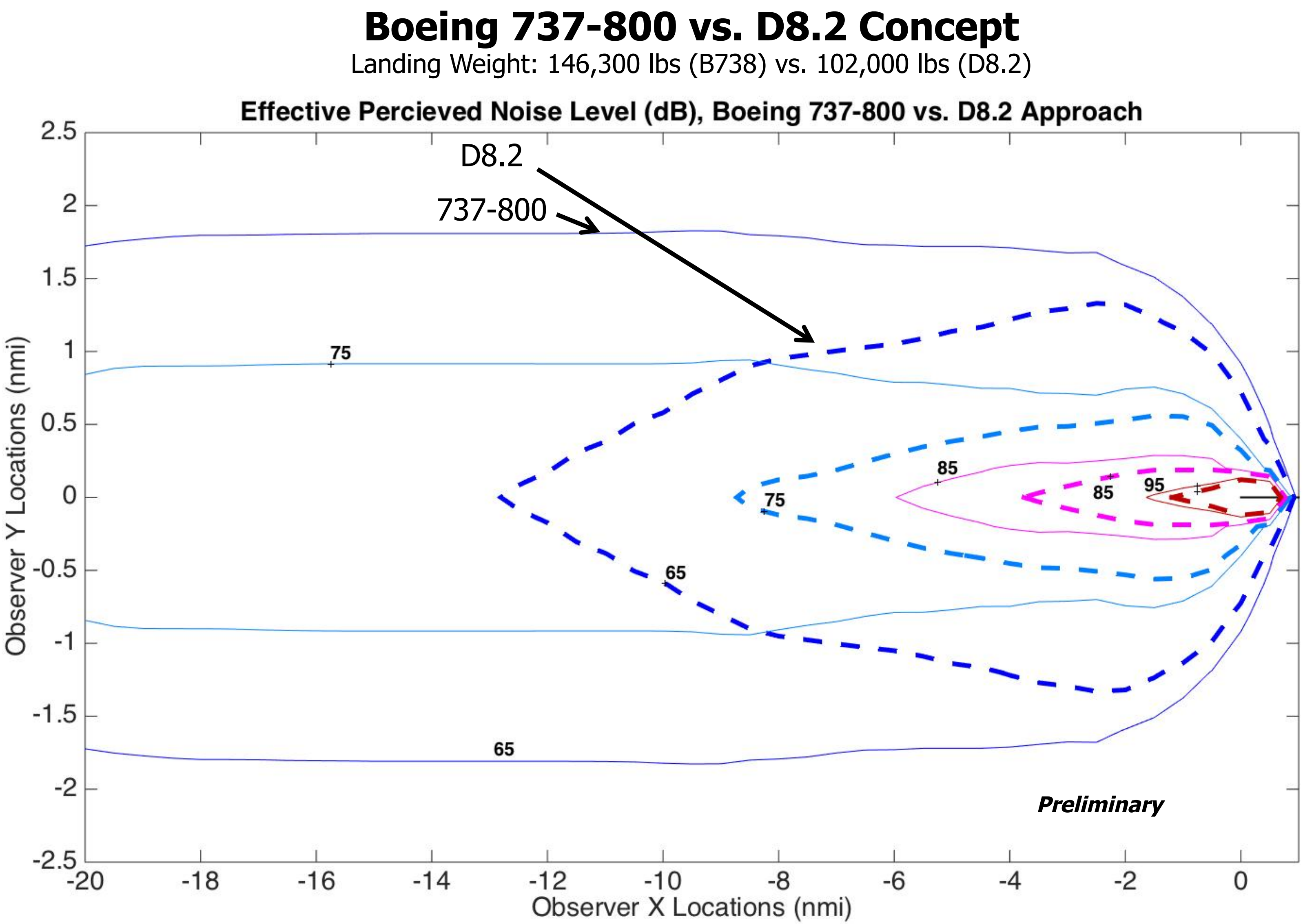
Figure: Boeing 737-800, from Boeing.com

Figure: D8 Aircraft Concept, from Aurora Flight Sciences

Boeing 737-800 vs. D8.2 Concept Aircraft Approach Profile



Boeing 737-800 vs. D8.2 Concept Aircraft: Noise Contour Comparison



Moving Forward

- Continue developing flight procedure generator
- Continue validating the TASOPT/ANOPP program noise results with FAA data for more aircraft types
- Use TASOPT/ANOPP program for computation of noise for more aircraft types and operational procedures

Acknowledgements and References

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  - Flavio Leo & Frank Iacovino - Massport

- **References:**
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  - Dumont, J., Reynolds, T., Hansman, J., “Analyzing Opportunities and Barriers of Delayed Deceleration Approach Procedures to Reduce Fuel Burn.” 12th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Indianapolis, IN (2012)

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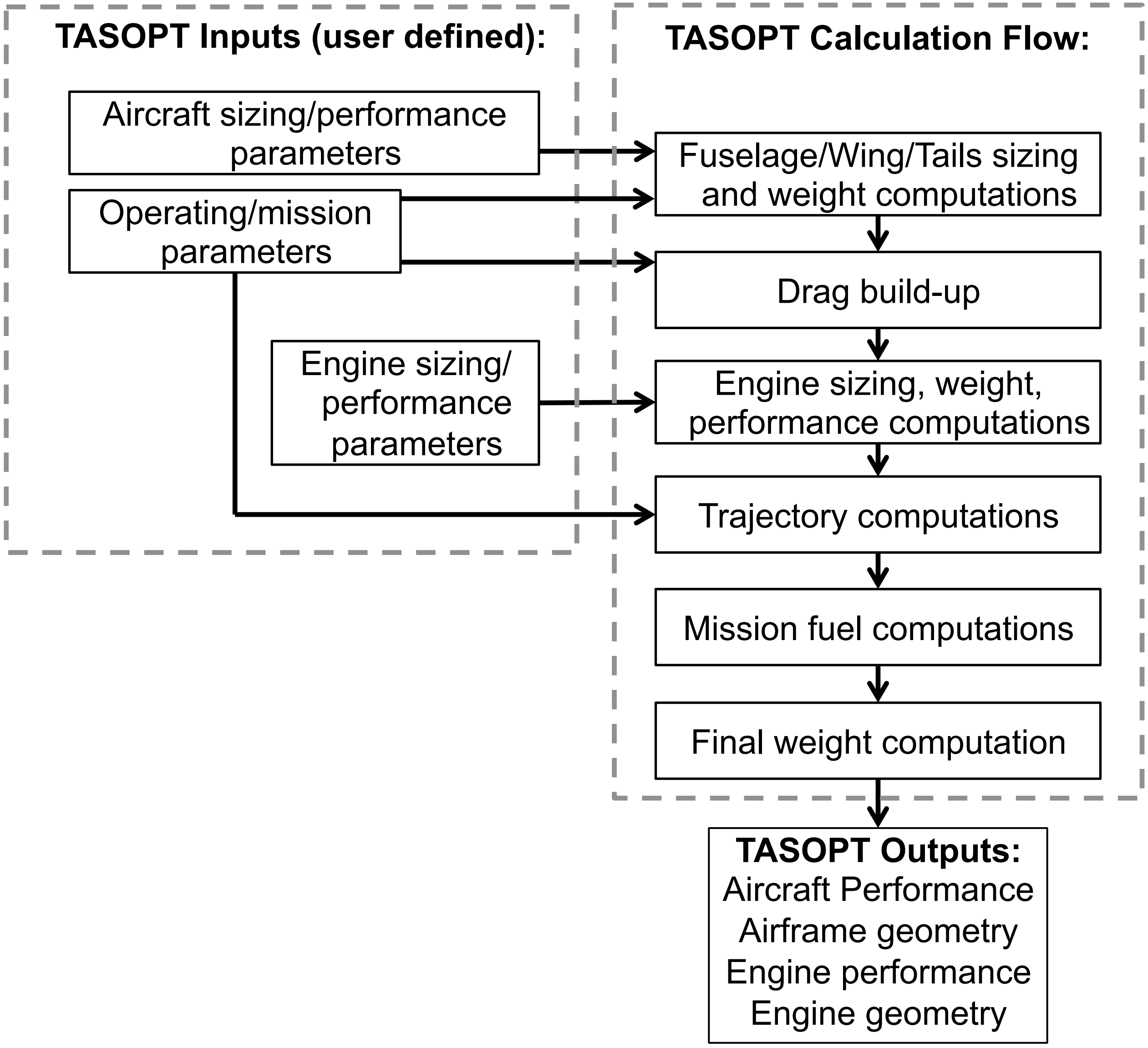
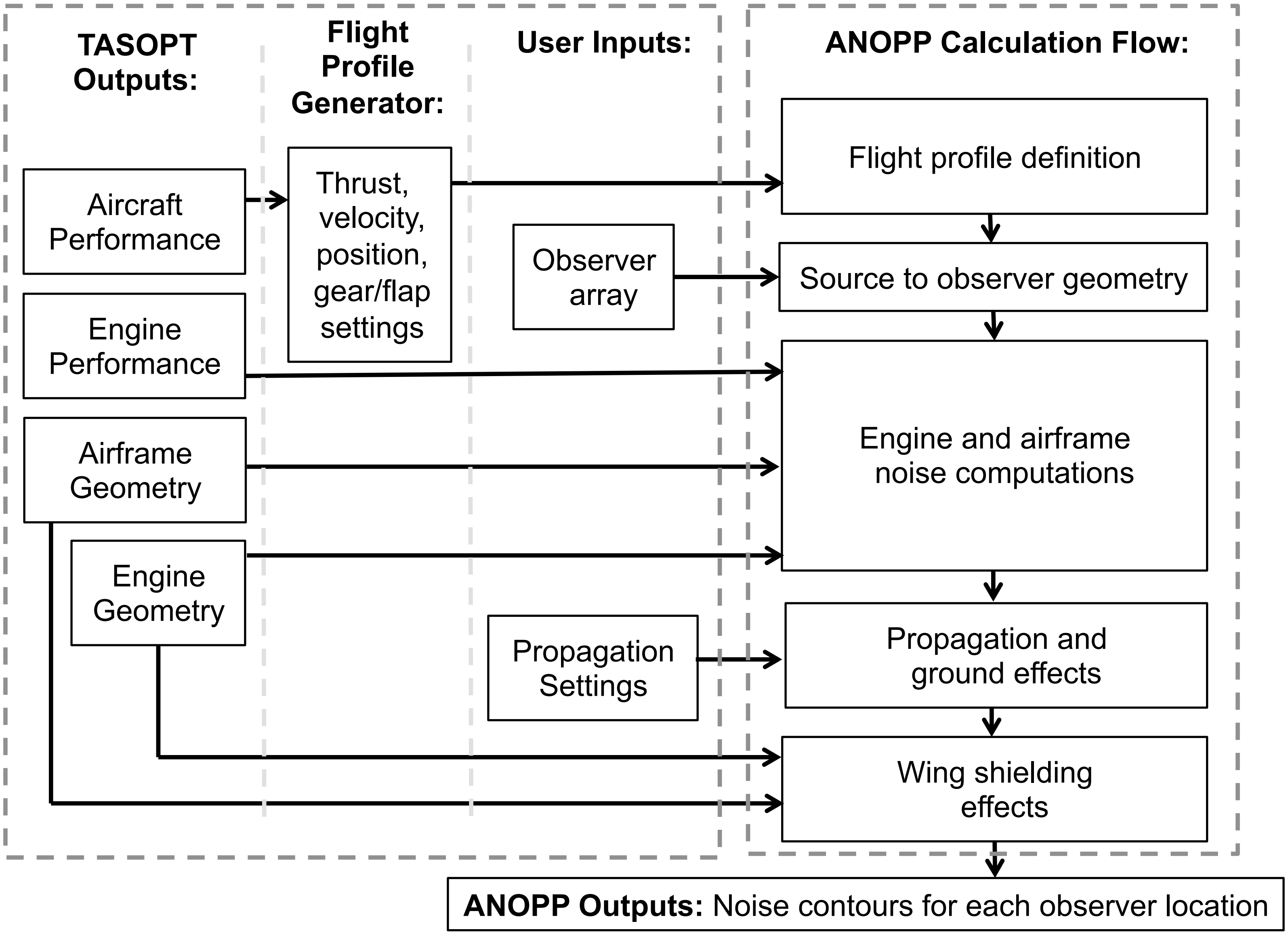
Appendix

TASOPT Calculation Flow

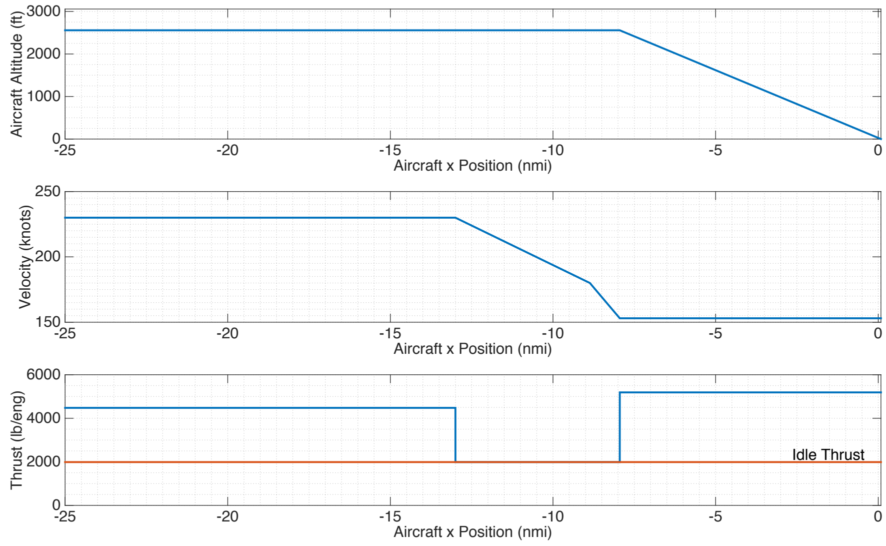


ANOPP Calculation Flow



Flight Profile Generator: Detailed Methodology

- **Goal: to generate position, velocity, and thrust of an aircraft flight profile from a combination of user specified requirements at each profile segment, including:**
  - Flap and gear settings: $\delta_{flap}, \delta_{gear}$
  - Segment end velocity: V_{end}
  - Deceleration: a
  - Thrust: T
  - Glideslope: γ
  - Segment end position: x_{end} or z_{end}



Sample Approach Profile: Boeing 737-800

- **The user initially specifies:**
  - Aircraft weight, wing area, air density: W, S, ρ
  - Drag coefficients: $C_D(\delta_{flap}, \delta_{gear}, C_L)$
  - Initial position, altitude, velocity: $x_{start}, z_{start}, V_{start}$
  - Number of profile segments

Flight Profile Generator: Computation Methodology

- **At each segment:**

The user specifies:

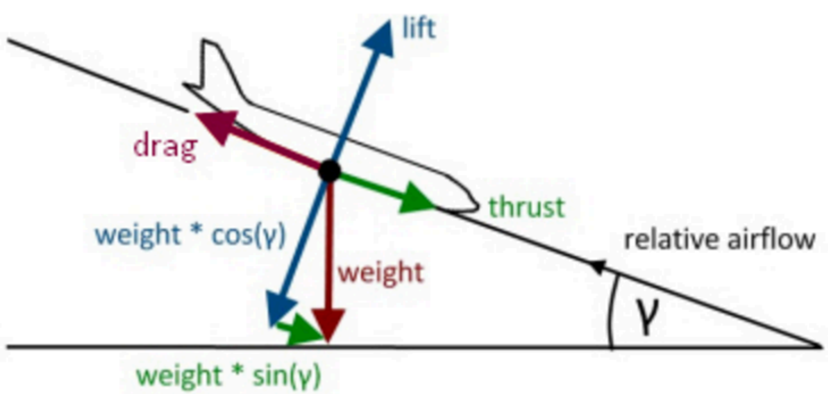
$\delta_{flap}, \delta_{gear}$

One of: a, V_{end}, or T

& two of: x_{end}, z_{end}, or γ

The generator computes:

remaining three variables not yet specified, using the equations below:



Segment sign conventions; negative value of γ indicates climb

$$a = \frac{\sum F}{m} = \frac{T + W\sin(\gamma) - D}{W/g}$$

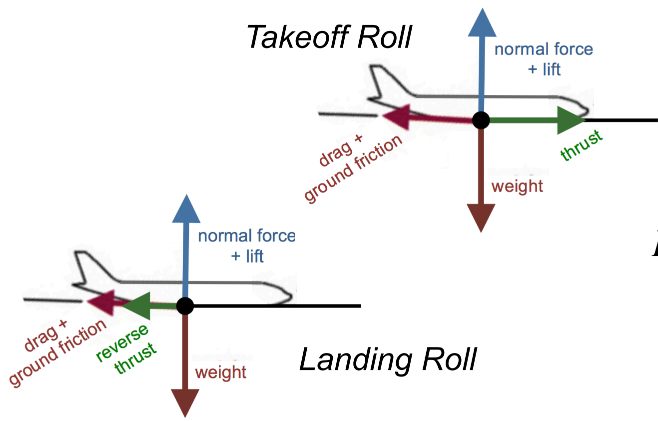
$$\frac{(V_{end})^2 - (V_{start})^2}{2a} = \frac{(x_{end} - x_{start})}{\cos(\gamma)} = \frac{(z_{end} - z_{start})}{\sin(\gamma)}$$

$$D = \frac{1}{2}\rho V^2 S C_D(\delta_{flap}, \delta_{gear}, C_L) \qquad C_L = \frac{W\cos(\gamma)}{\frac{1}{2}\rho V^2 S}$$

- $x_{end}, z_{end}, V_{end}$ **of one segment become** $x_{start}, z_{start}, V_{start}$ **of the next segment**

Flight Profile Generator: Computation Methodology

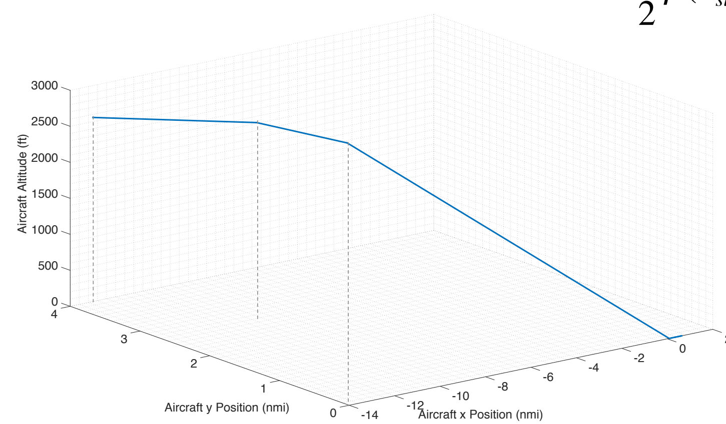
- **To get thrust (or reverse thrust) profile T ($T_{Reverse}$) on the runway, the user specifies (with V_{start} the velocity upon liftoff or upon touchdown):**
  - Takeoff/Landing roll length: L_{Roll}
  - Runway coefficient of friction: μ



$$\frac{(V_{start})^2}{2L_{Roll}} = a \qquad a = \frac{\sum F}{m} = \frac{-T / +T_{reverse} + D + \mu(W-L)}{W/g}$$

$$D = \frac{1}{2}\rho V^2 S C_D(\delta_{flap},\delta_{gear},C_L) \qquad L = \frac{1}{2}\rho V^2 S C_{L,start} \qquad C_{L,start} = \frac{W}{\frac{1}{2}\rho(V_{start})^2 S}$$

- **Lastly, the user specifies the the lateral aircraft position profile $y(s)$ with $s = \sqrt{x^2 + z^2}$**



Sample Approach Profile: Boeing 737-800 including Landing Roll

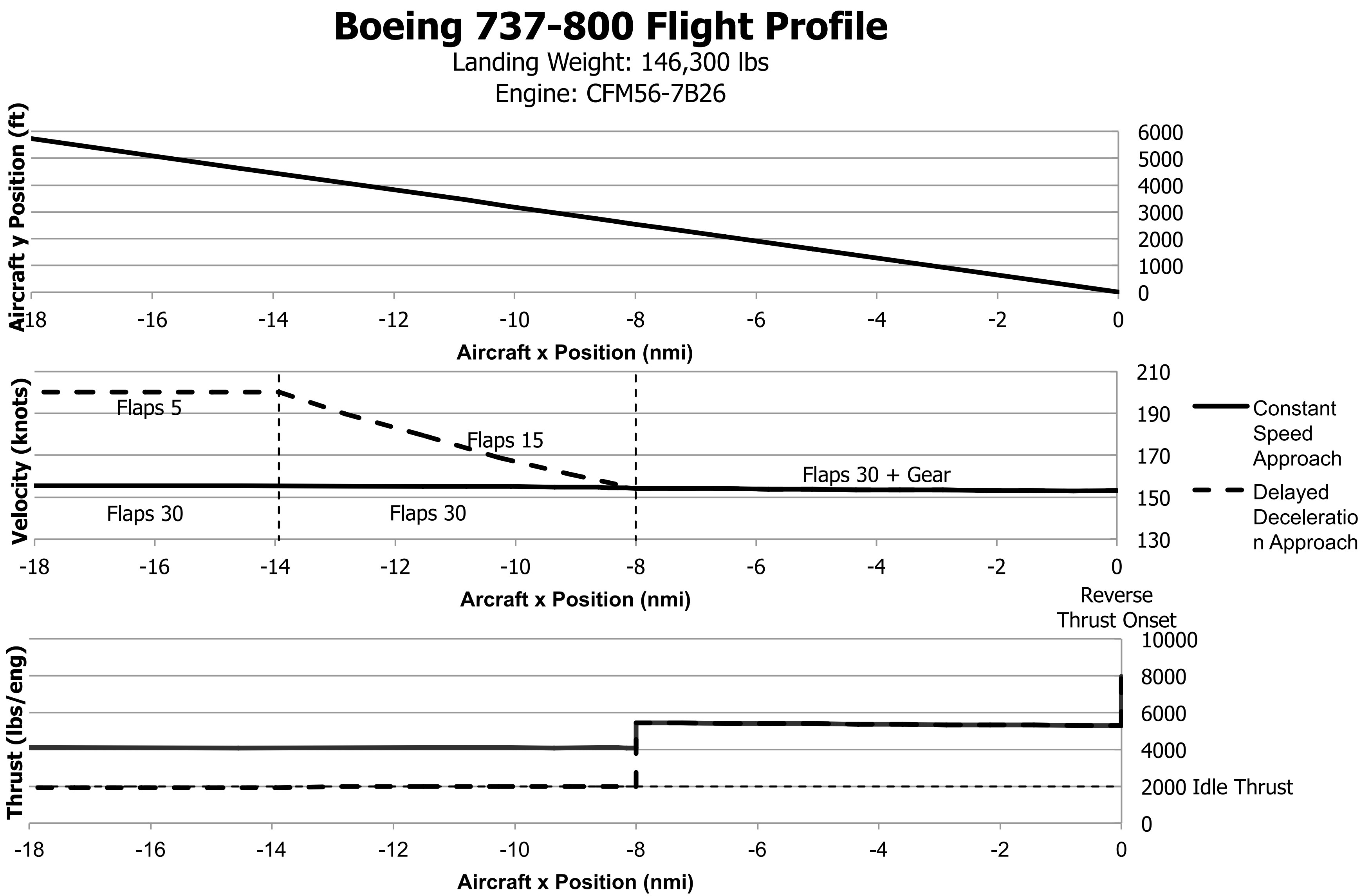
Drag Coefficients for Flight Profile Generator

- **Drag coefficients for existing aircraft currently obtained from Base of Aircraft DAta (BADA)**
  - BADA provides aerodynamic drag coefficients for various flap and gear configurations of supported aircraft types:

```
CC====== Aerodynamics =================================================/
CC Wing Area and Buffet coefficients (SIM)                             /
CCndrst Surf(m2)      Clbo(M=0)       k          CM16                  /
CD 5    .12465E+03   .12454E+01   .55567E+00   .00000E+00              /
CC    Configuration characteristics                                    /
CC n Phase  Name     Vstall(KCAS)     CD0         CD2         unused   /
CD 1 CR    Clean     .14900E+03   .25452E-01   .35815E-01   .00000E+00 /
CD 2 IC    Flap1     .11900E+03   .26200E-01   .44800E-01   .00000E+00 /
CD 3 TO    Flap5     .11700E+03   .35700E-01   .42300E-01   .00000E+00 /
CD 4 AP    Flap15    .10900E+03   .49200E-01   .42400E-01   .00000E+00 /
CD 5 LD    Flap30    .10700E+03   .68900E-01   .40400E-01   .00000E+00 /
CC    Spoiler                                                          /
CD 1       RET                                                         /
CD 2       EXT                                 .00000E+00   .00000E+00 /
CC    Gear                                                             /
CD 1       UP                                                          /
CD 2       DOWN                   .24900E-01   .00000E+00   .00000E+00 /
CC    Brakes                                                           /
CD 1       OFF                                                         /
CD 2       ON                                  .00000E+00   .00000E+00 /
```

$$C_D = C_{D0}(\delta_{flap}, \delta_{gear}) + C_{D2}(\delta_{flap}) * (C_L)^2$$

Delayed Deceleration Approach Profile: Continuous 3-degree Glideslope



Impact of Delayed Deceleration on Noise Contour